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THE CSI 1kW METAL-HALIDE DISCHARGE LAMP: measurements and predicted effects of intensity ripple using sinusoidal lamp excitation

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Summary

A description is given of measurements of the light intensity ripple characteristics shown by the Thorn CSI 1 kW metal-halide discharge lamp when excited from a sinusoidal power source at various frequencies in the range 50 Hz to 1000 Hz. Operating conditions which reduce motion picture film exposure variations to acceptable limits in the presence of this ripple component are discussed.

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1. Introduction

The intensity of light from a lamp varies at a frequency of twice that of its supply. This 'intensity ripple' component can[1] give rise to cyclic exposure variations when the lamp is used as a light source for motion-picture film work, and these exposure variations can in turn produce fluctuations in the luminance of the reproduced picture. If the magnitude of the ripple component is known, the conditions under which filming takes place can be arranged[2,3a] so that these exposure variations are reduced to imperceptibility.

This Report gives details of the magnitude of intensity ripple in light from a Thorn CSI 1 kW[4,5] metal-halide discharge lamp* as a function of lamp supply frequency, when excited from a sinusoidal alternating supply. The experimental techniques used for obtaining these results are described elsewhere.[3] The spectral response of the photoreceptor used in the equipment[3b] approximated, in the 'broad-band' case, to the overall response of typical colour film** and in each of the 'narrow-band' bases to the responses of the individual dye-forming layers of the film. The latter are referred to as the 'red', 'green' and 'blue' responses, corresponding to exposure resulting in the formation of the cyan, magenta and yellow dye layers respectively.

All the ripple measurements were made using an inductive ballast impedance of approximately 15 ohms at the supply frequency, with the object of obtaining operation at the rated power when connected to a 240 V r.m.s. supply. Measurements using a 50 Hz supply were made using a ballast arrangement consisting of three Thorn 'Sodium Ballasts' type AME 53230-T connected in parallel. This ballast arrangement is used commercially for CSI lamp control. At higher frequencies a demountable choke with adjustable air gap was used. In practice it was found that when operating at 50 Hz the lamp dissipated 878 watts when 240V r.m.s. was applied to the lamp and ballast combination, while for operation at 500 Hz an upper power limit of 820 watts was set by saturation of the choke core. Since the ripple ratio magnitude is not strongly dependent on lamp dissipated power (see Section 2), the results obtained under these running conditions are closely indicative of lamp performance up to the maximum rated lamp dissipation, and in this Report are quoted as applying to operation at the nominal rated power of 1 kW.

* mounted in a PAR-64 sealed-beam reflector to form a pre-focused unit.

** Note that this spectral response is broader than the standard photopic relative spectral luminous efficiency (V_λ) curve.

2. Intensity ripple characteristics

2.1. General

Intensity ripple magnitudes are expressed in terms of the ripple ratio p, where

$$p = \frac{\text{minimum light intensity}}{\text{maximum light intensity}}$$

Measurements of ripple ratio were taken to explore the effects of the following variables:

(a) The lamp power supply frequency

(b) The power dissipated in the lamp

(c) The spectral response of the photoreceptor used for the measurements

(d) The position of the photoreceptor in relation to the beam of light from the pre-focused unit.

2.2. Measurements in diffused light

Most of the measurements of ripple ratio in diffused light were made by positioning the photoreceptor outside the mean beam from the pre-focused unit, so that no component of illumination was received from the reflector. A few measurements were made by allowing all light emitted by the lamp to fall on a diffusely-reflecting white surface, the photoreceptor being placed to receive light scattered from this surface. In both cases the results of such measurements should be directly comparable with those made on the bare lamp.

Relationships between the ripple ratio in diffused light and the power dissipated in the lamp are shown for three supply frequencies, and using the broad-band spectral response, in Fig. 1. As expected, the ripple ratio increases (i.e. 'depth of modulation' of the ripple component decreases) as the supply frequency is increased. It may however be noted that the reduction in the amount of ripple is far less than might be expected from the increase in supply frequency. For example, with the lamp running at its nominal rating, an increase by a factor of 20 in supply frequency only causes an increase of ripple ratio by a factor of about 2·1; this corresponds to a reduction in the magnitude of the alternating ripple component by a factor of about 3·1. Fig. 1 also shows that the ripple ratio value depends to some extent on the power dissipated in the lamp, the value rising as the lamp power is reduced and reaching a maximum value at about 500–600 watts. There is thus no likelihood of a reduction in ripple ratio, and a consequent increased risk of the occurrence of significant

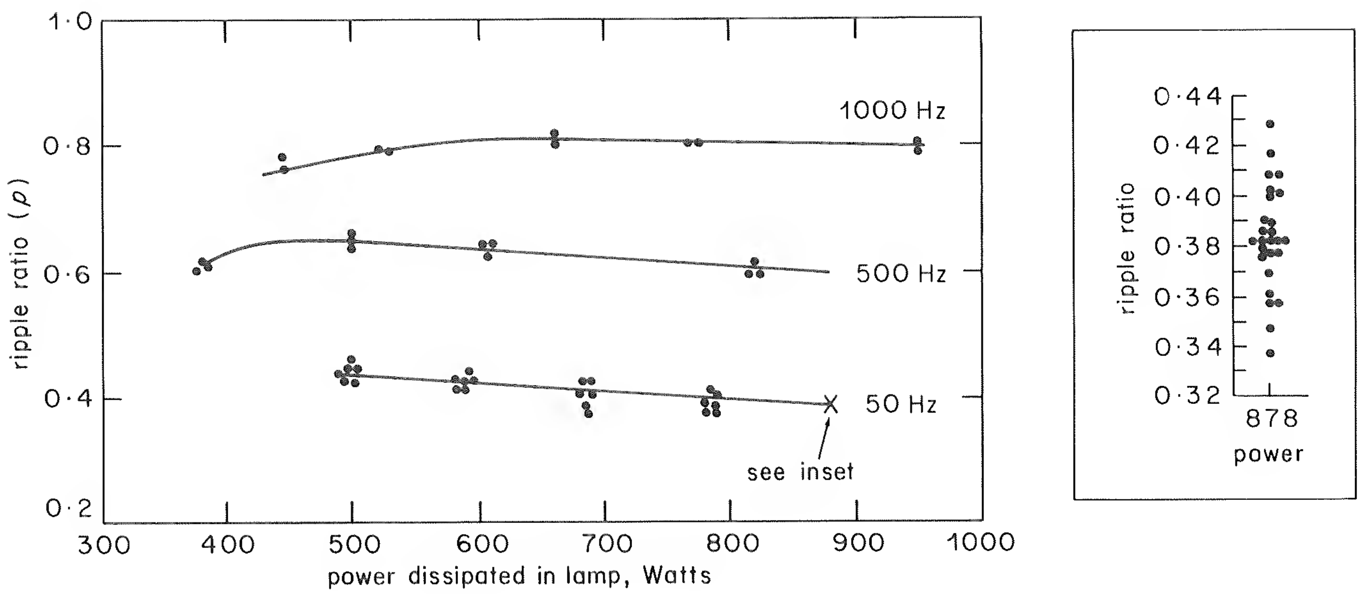


Fig. 1 - CSI 1 kW lamp: variation of ripple ratio with dissipated power, for different supply frequencies, using broad-band receptor characteristic and diffused light

● individual values x mean value

film exposure variations (see Section 3), if the lamp is inadvertently under-run. It should, however, be noted that the spectral power distribution of light from the lamp changes significantly with change of dissipated power, and that the light emitted when the lamp is significantly under-run may therefore be less suitable for use with colour film than when the lamp is run at its nominal rating.

Figs. 2, 3 and 4 again show relationships between ripple ratio in diffused light and lamp dissipated power for three supply frequencies, but in these cases using the red, green and blue narrow-band equipment responses respectively. Comparing in turn each of these figures with Fig. 1 shows that, for any given combination of supply frequency and dissipated power, the ripple ratios obtained using the red and blue responses are nearly equal to each other and somewhat higher than the value obtained using the broad-band response, while the ratio obtained using the green response is rather less than that obtained with the broad-band response. This behaviour is probably due to a change with wavelength in the relative contributions from individual additives to the total light output from the lamp. These differing values of narrow-band ripple ratio indicate that film exposure variations will strictly speaking give rise rise to fluctuations of displayed chromaticity in addition to fluctuations of picture luminance; in practice, however, such chromaticity fluctuations are likely to be of negligible importance.

2.3. Measurements in the centre of the beam

Because of the high intensity of light in the centre of the beam from the pre-focused unit, measurements of ripple ratio in this position were made using light scattered from a magnesium carbonate surface placed in the beam. The edges of this surface subtended an angle of approximately five degrees at the centre of the lamp with respect to the axis of measurement. The relationship between the ripple ratio at beam centre and the power dissipated in the lamp for a supply frequency of 50 Hz, using the broad-band spectral response, is shown in Fig. 5. The results of measurements of ripple ratio at beam centre for supply frequencies of 500 Hz and 1000 Hz, again using the broad-band spectral response, are also shown in Fig. 5; in these cases measurements were only made at the highest power used for each supply frequency (see Section 1). Comparing Fig. 5 with Fig. 1 shows that the ripple ratios obtained in the centre of the beam are considerably lower than the values obtained in diffused light under corresponding conditions of supply frequency and dissipated power. This difference must be taken into account when considering applications of these lamps which involve the use of a highly-focused beam; this aspect is discussed in Sections 3 and 4.

2.4. The effect of lamp current waveform

Ripple ratio magnitude is affected by the waveform of the current passing through the lamp. A change in this waveform from sinusoidal towards a more 'pulse-like' character will reduce the value of ripple ratio, other conditions remaining the same. Conversely, a change in the direction of a 'square' current waveform will increase the value of ripple ratio. Although in principle a true square current waveform, such that lamp current remains at its peak value for the complete duty cycle but periodically reverses direction, will give unity ripple ratio (i.e. no ripple), the reversal of direction of current must in practice occupy a finite time, and consequently the intensity ripple component can never be eliminated completely. At the other extreme, the use of a resistive ballast in conjunction with a sinusoidal supply tends to give rise to a pulse-like current waveform (especially at lower supply frequencies) and consequently a lower value of ripple ratio. The use of each

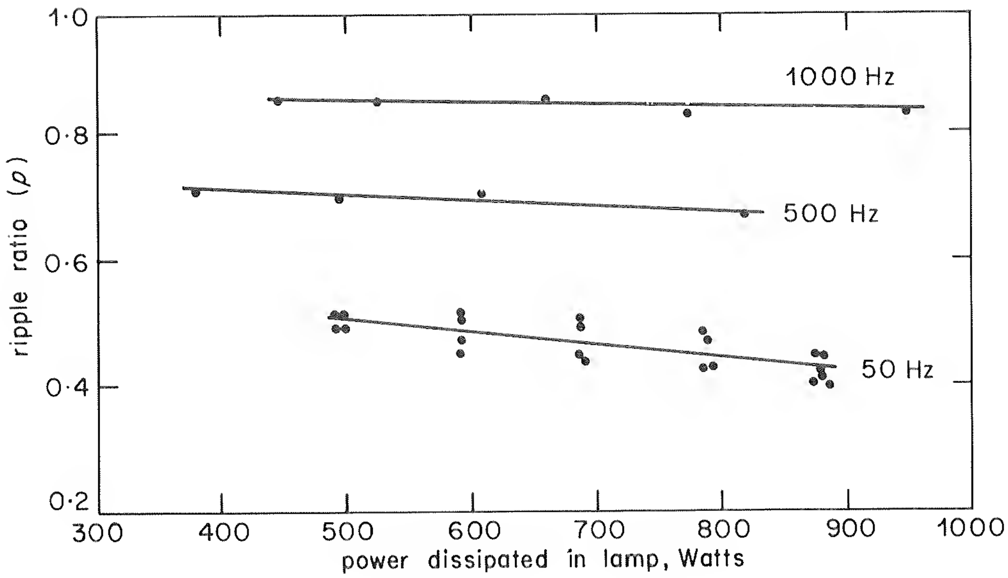


Fig. 2 - 'Red' narrow-band receptor characteristic

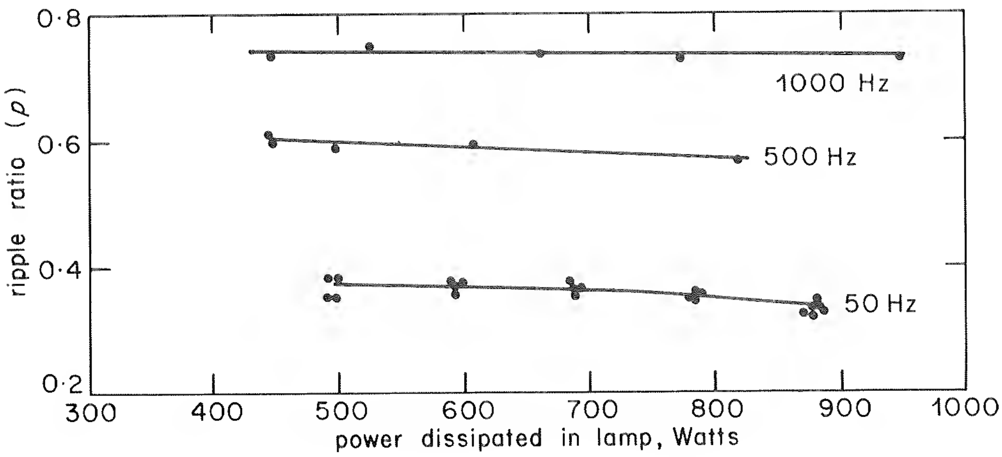


Fig. 3 - 'Green' narrow-band receptor characteristic

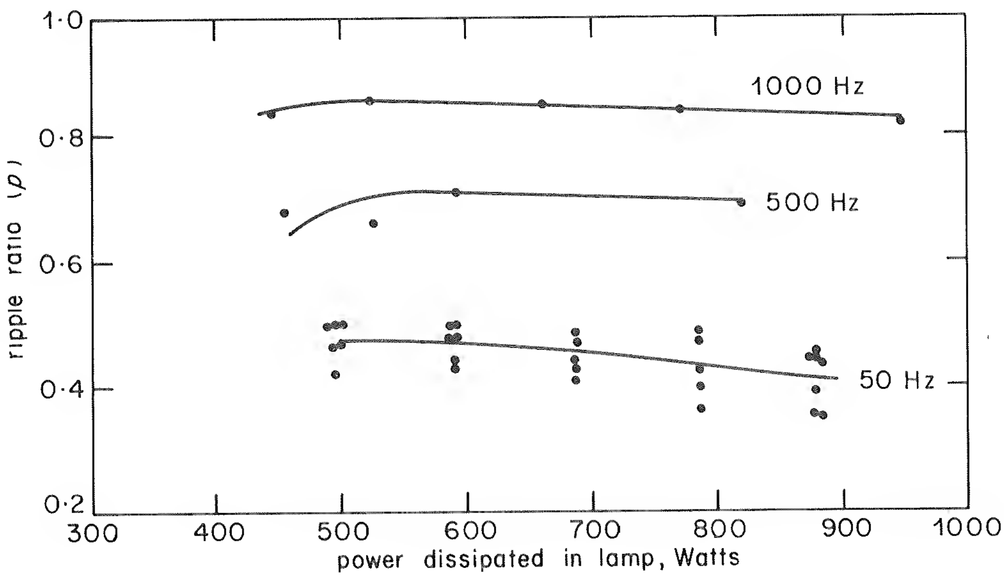


Fig. 4 - 'Blue' narrow-band receptor characteristic

Figs. 2–4 - CSI 1 kW lamp: variation of ripple ratio with dissipated power, for different supply frequencies, using narrow-band receptor characteristics and diffused light

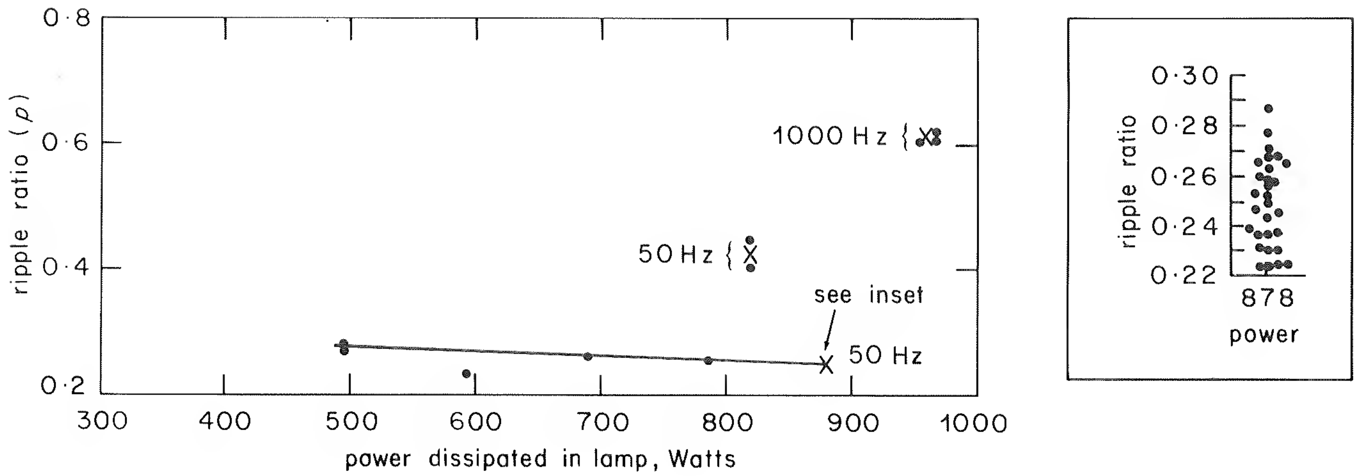


Fig. 5 - CSI 1 kW lamp: variation of ripple ratio with dissipated power, for different supply frequencies, using broad-band receptor characteristic and beam-centre light

● individual values x mean values

ballasting arrangements at low supply frequencies is therefore to be avoided:* wastage of power in the ballast is also very relevant in this case.

3. Conditions for imperceptibility of picture luminance fluctuations

3.1. General

The operating conditions for which picture luminance fluctuations remain imperceptible are expressed in terms of lamp supply frequency and intensity ripple ratio, and camera frame frequency and shutter angle. The replay frame frequency is also significant if different from the camera frame frequency (e.g. in the case of slow-motion or accelerated-motion filming), but in this Report these two frequencies are assumed to be equal. The assumption is also made that the ripple component is sinusoidal: this is not strictly true in practice (especially at low supply frequencies) but the errors introduced by this assumption are reasonably small and are in any case in a direction which decreases the visibility of the picture luminance fluctuations.

The methods of determining the limits within which picture luminance fluctuations remain imperceptible have been described in detail elsewhere.[2,3a]

3.2. Operation using supply frequencies in the range 43–67 Hz

Lamp supply frequencies and camera shutter angles for which picture luminance fluctuations remain imperceptible are shown in Figs. 6 – 8 for a camera frame frequency of 24 Hz and Figs. 9 – 11 for a camera frame frequency of 25 Hz. These operating conditions refer to the value of ripple ratio (p = 0·4) quoted by the manufacturer. From Fig. 1 it can be seen that this value is well within the range obtained, for diffused light, with a lamp supply frequency of 50 Hz, the use of the wide-band spectral characteristic and with the lamp running at its nominal rating The ripple ratio value varies little with frequency over the supply frequency range under consideration and the value obtained at 50 Hz has therefore been assumed to hold over the whole supply frequency range covered by these figures. Picture luminance fluctuations will be imperceptible if the operating conditions fall within the unshaded areas of these figures.

Strictly speaking, Figs. 6 – 8 are valid only if the camera frame frequency is precisely 24 Hz. Figs. 9 – 11 refer similarly to a camera frame frequency of precisely 25 Hz. A departure of the camera frame frequency from either of these nominal values by a factor k can be allowed for by multiplying the lamp supply frequency values shown in the appropriate figure by the same factor k. In some circumstances, however, only the nominal camera frame frequency (24 Hz or 25 Hz) may be known, without detailed knowledge of the deviations from this frequency which may be expected in normal operation. Discussion with the manufacturers of the CSI 1 kW lamp has indicated that, in their experience based on five years' use of these lamps in feature film production, no perceptible picture luminance fluctuations have ever been evident when using these lamps, provided that the operating conditions (camera shutter angle and lamp supply frequency) are arranged to fall midway between the boundaries of the unshaded areas in Figs. 6 – 11. For example, Fig. 10 shows that for a nominal camera frame frequency of 25 Hz and shutter angle of 172°, operation using a lamp supply frequency of 52·3 Hz is indicated by the manufacturers' experience as being appropriate for preventing the appearance of picture luminance fluctuations.

The short inner contours in Figs. 6 – 11 refer to operating conditions using beam-centre light (p = 0·25;

* Bourne[6] has shown that the use of series capacitative ballast at low supply frequencies also gives rise to a pulse-like current waveform; use of this arrangement will therefore also produce a lower ripple ratio value.

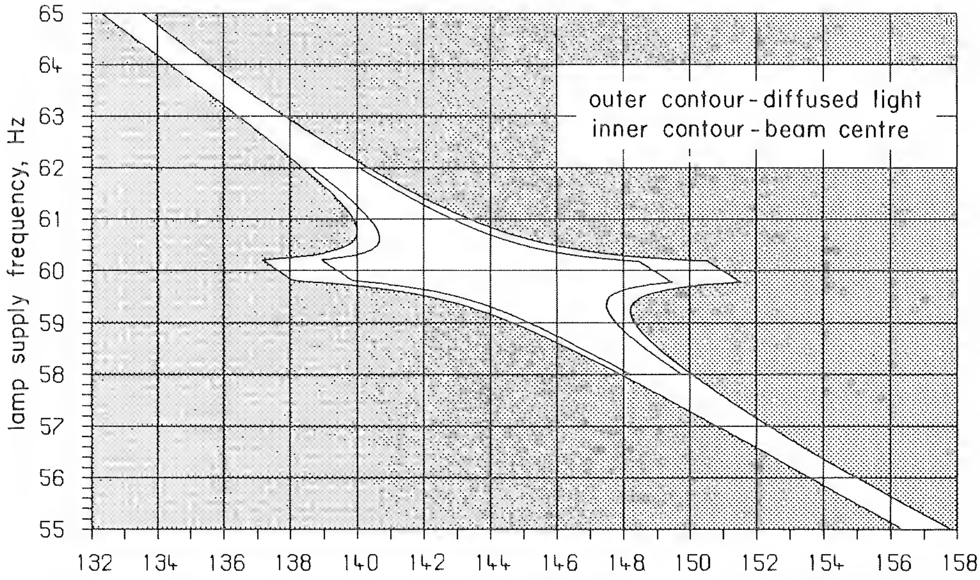


Fig. 6 - Shutter angles 132° – 158° (Ripple asymmetry: see Section 4)

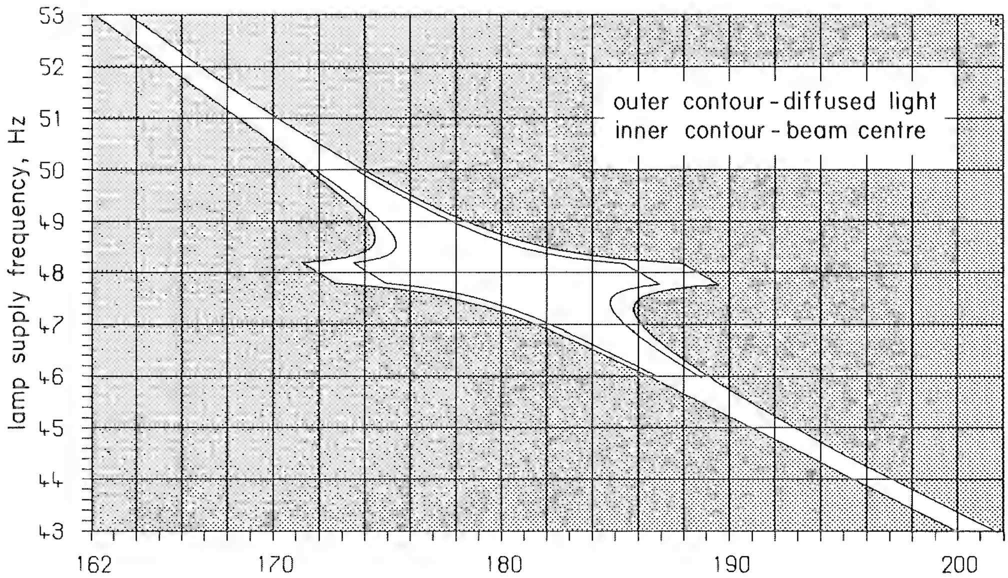


Fig. 7 - Shutter angles 162° – 202° (Ripple asymmetry not significant)

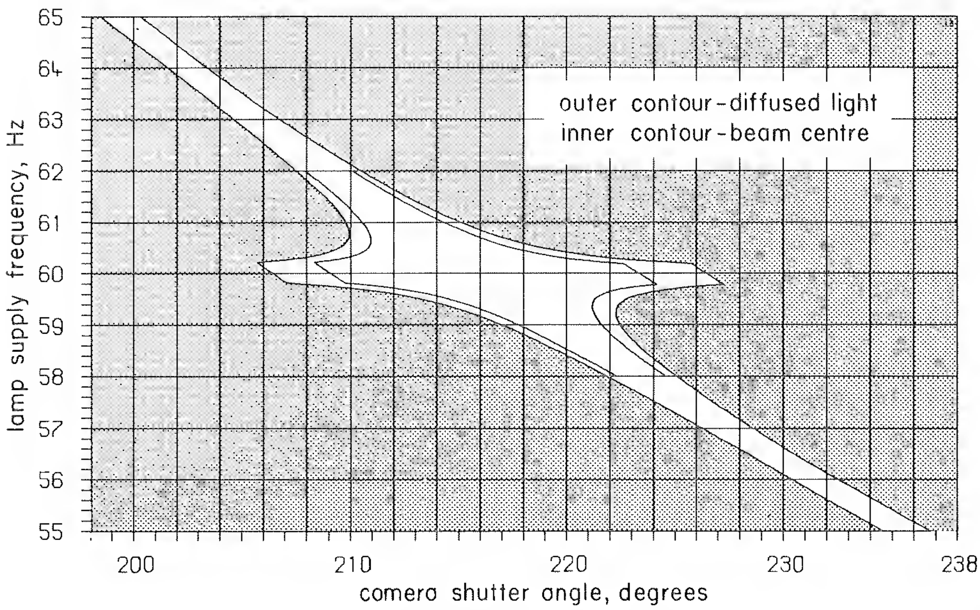


Fig. 8 - Shutter angles 198° – 238° (Ripple asymmetry: see Section 4)

Figs. 6–8 - CSI 1 kW lamp: supply frequency limits as a function of camera shutter angle. Camera frame frequency = 24 Hz

Fig. 9 - Shutter angles 132° – 156° (Ripple asymmetry: see Section 4)

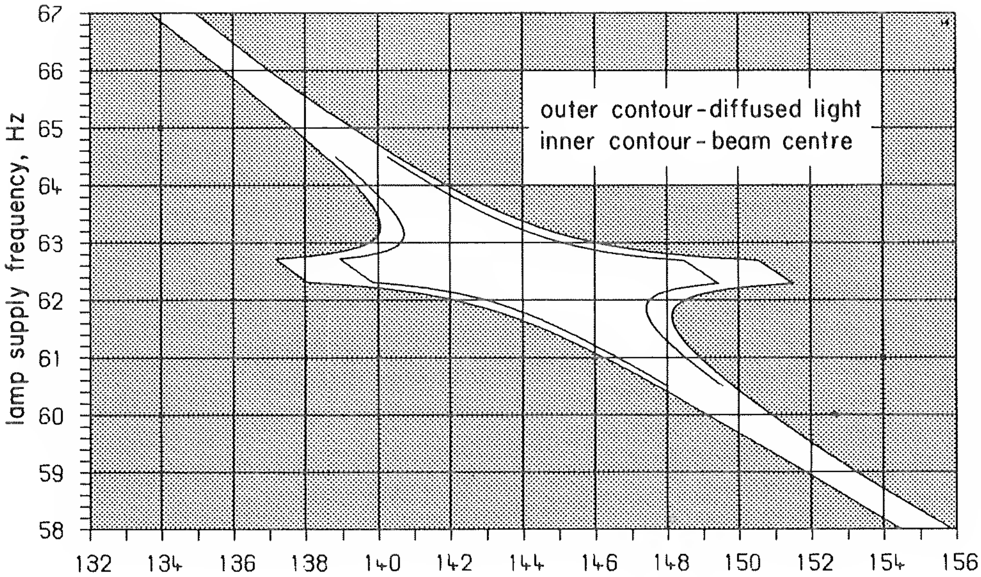


Fig. 10 - Shutter angles 162° – 202° (Ripple asymmetry not significant)

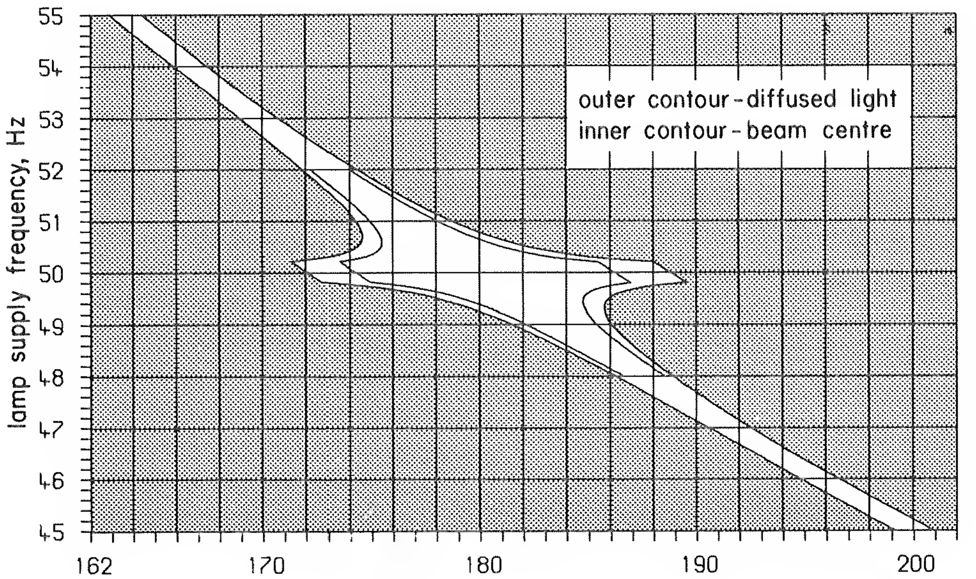
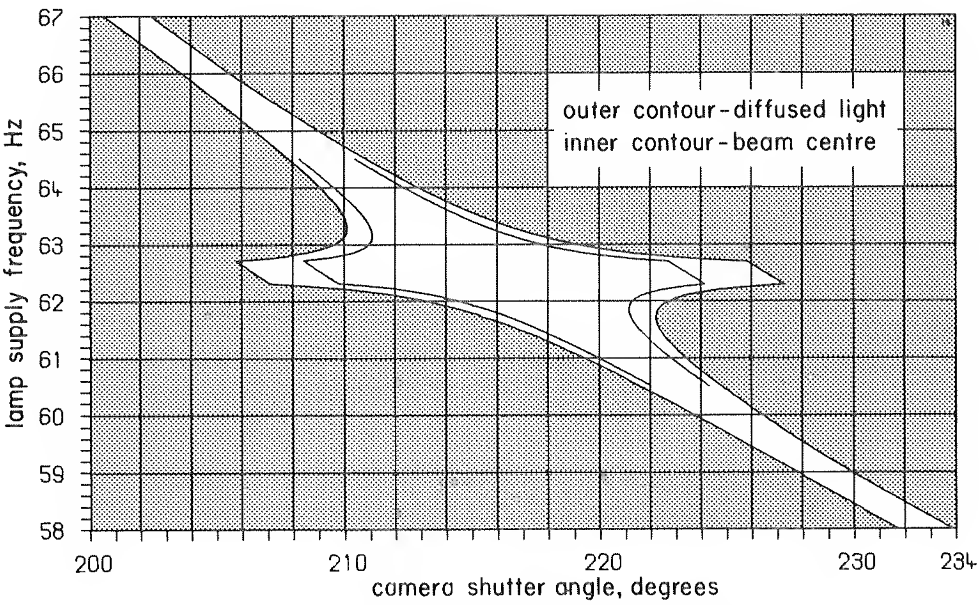


Fig. 11 - Shutter angles 200° – 234° (Ripple asymmetry: see Section 4)



Figs. 9–11 - CSI 1 kW lamp: supply frequency limits as a function of camera shutter angle. Camera frame frequency = 25 Hz

see Fig. 5). Other parameters (supply frequency, spectral characteristics and lamp power) are as described above. In this case picture luminance fluctuations will be imperceptible if the operating conditions fall inside these short contours.

For operating using shutter angles between 83° – 99° and 247° – 299°, or when referring to other ripple ratio values for diffused light shown by the lower curves in Figs. 1 – 4, reference should be made to the detailed discussion[2a] of suitable operating conditions in this range of supply frequencies.

3.3. Operation using high supply frequencies

If lamp supply frequencies much higher than 50 – 60 Hz are used, it is possible to use the lamp as a light source for motion-picture film work without taking into account, each time the lamp is used, the relationships between the lamp and camera parameters discussed in Section 3.1. The minimum 'safe' supply frequency for which this mode of operation becomes possible may be found by plotting the relation between ripple ratio and lamp supply frequency on a SLOT* diagram.[3a] In such a diagram (e.g. Fig. 12) a safe operating condition (in respect of freedom from significant exposure variations) is indicated if the practical relationship between ripple ratio and lamp supply frequency lies above and to the right of the relevant shutter-angle contour (shutter-angle contours run from top-left to bottom-right of the diagram). The positions of these contours on the diagram depend on the camera frame frequency as well as the shutter angle. It may however be shown that, for a given value of ripple ratio, the safe lamp

* Safe Lamp Operating Technique

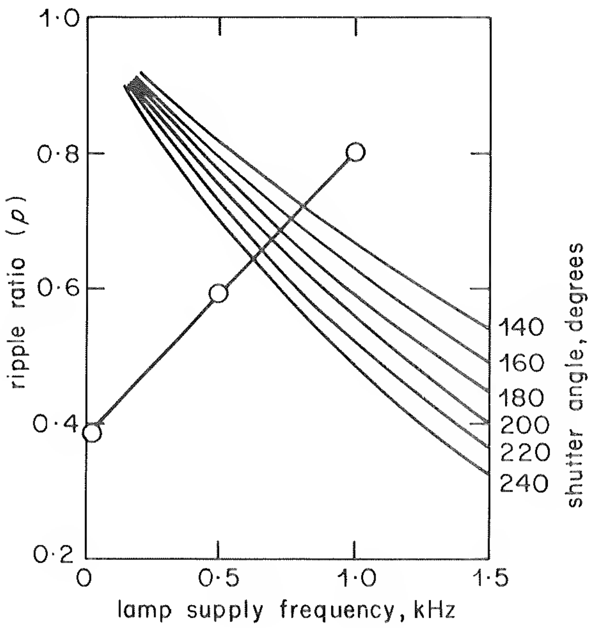


Fig. 12 - CSI 1 kW lamp: SLOT diagram for camera frame frequency of 25 Hz and ripple ratio values measured in diffused light

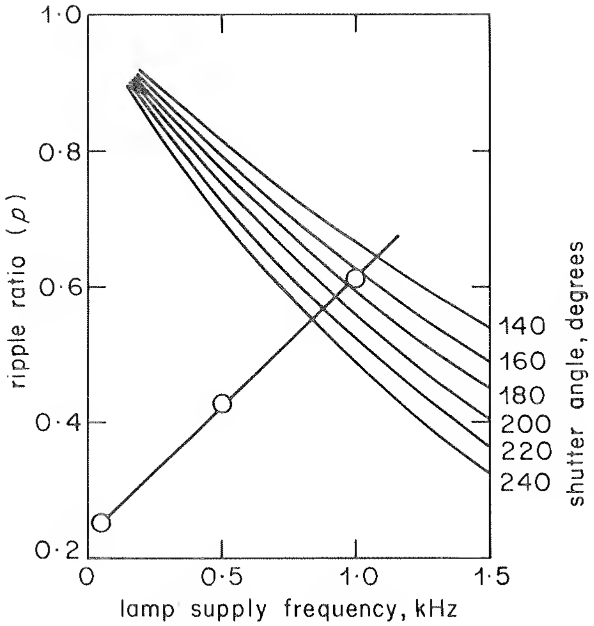


Fig. 13 - CSI 1 kW lamp: SLOT diagram for camera frame frequency of 25 Hz and ripple ratio values measured in beam-centre light

supply frequency decreases with decrease of camera frame frequency. Safe operating conditions found for a particular frame frequency will therefore also hold for lower frame frequencies. In the present context, operation at a camera frame frequency of 24 Hz need not be considered separately, as safe operating conditions found for a frame frequency of 25 Hz will also apply in the case of the lower frame frequency. Fig. 12 therefore shows a SLOT diagram, for a frame frequency of 25 Hz, for the condition in which scene illumination is by diffused light. The practical ripple ratio values (open circles) refer, as in Section 3.2, to use of the wide-band spectral response and to the lamp running at its nominal rating. Since it is evident from Fig. 12 that safe operating conditions found for a particular shutter angle will also hold for greater shutter angles, it can be seen that a lamp supply frequency of 750 Hz will give safe operating conditions for camera frame frequencies of 25 Hz or lower, and shutter angles of 160° or greater.

Fig. 13 shows the SLOT diagram corresponding to beam centre illumination (see Fig. 5). Other parameters are as described above. Again considering shutter angles of 160° or greater, it can be seen that the minimum safe lamp supply frequency is increased to 1000 Hz under these conditions. There is therefore a risk of picture luminance fluctuations appearing in scene areas illuminated with light from the centre of a highly-focused beam if the lamp supply frequency lies between 750 Hz and 1000 Hz, even though other picture areas illuminated with diffused light should be free from such effects.

Practical relationships between ripple ratio in diffused light and lamp supply frequency, other than those shown in Figs. 12 – 13, can if required be derived from Figs. 1 – 4

and plotted on SLOT diagrams to derive appropriate safe lamp supply frequencies.

4. The effect of ripple asymmetry

Asymmetry of the ripple waveform is said to occur if successive maxima are alternately of higher and lower magnitude. Under certain operating conditions[2b,7] (e.g. with lamp supply frequencies in the range 55 – 65 Hz and camera frame frequency of 24 Hz as shown in Figs. 6 and 8, or with supply frequencies in the range 58 – 67 Hz and camera frame frequency of 25 Hz as shown in Figs. 9 and 11) the presence of ripple asymmetry can give rise to cyclic exposure variations, over and above those produced by the ripple component itself, which in turn can lead to the appearance of visible picture luminance fluctuations. The factors which control the appearance of such luminance fluctuations include the lamp supply frequency. However, in the particular operating conditions considered in Figs. 6, 8, 9 and 11, it can be shown[2c,2d] that the supply frequencies which give the greatest risk of picture luminance fluctuations due to ripple asymmetry are precisely those which give the greatest protection from luminance fluctuations due to the ripple component itself (i.e. supply frequencies close to 60 Hz using a camera frame frequency of 24 Hz, or close to 62·5 Hz using a camera frame frequency of 25 Hz). Because of the importance of obtaining as much protection as possible from the effects of the ripple component it is very likely that such lamp supply frequencies will be in use (furthermore, 60 Hz is a widely-used standard frequency for the public electricity supply). The use of such 'unfavourable' lamp supply frequencies must therefore be assumed when assessing the extent to which ripple asymmetry will give rise to picture luminance fluctuations.

Fifteen measurements of asymmetry ratio* were made in diffused light with the lamp powered from a 50 Hz

* Asymmetry ratio is defined as the ratio of the smaller to the larger ripple maximum value.

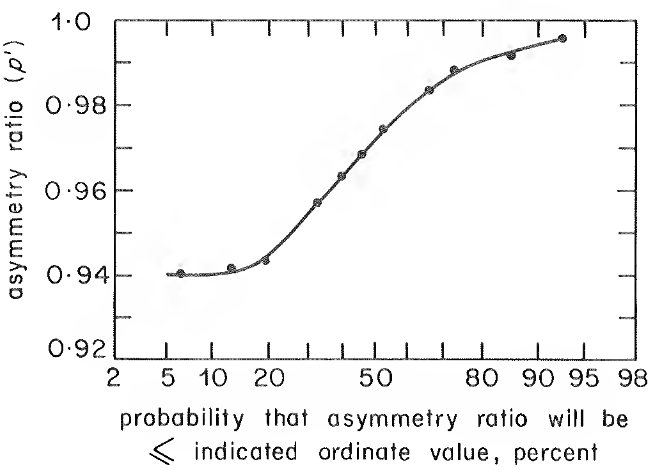


Fig. 14 - CSI 1 kW lamp: asymmetry ratio characteristics for diffused light

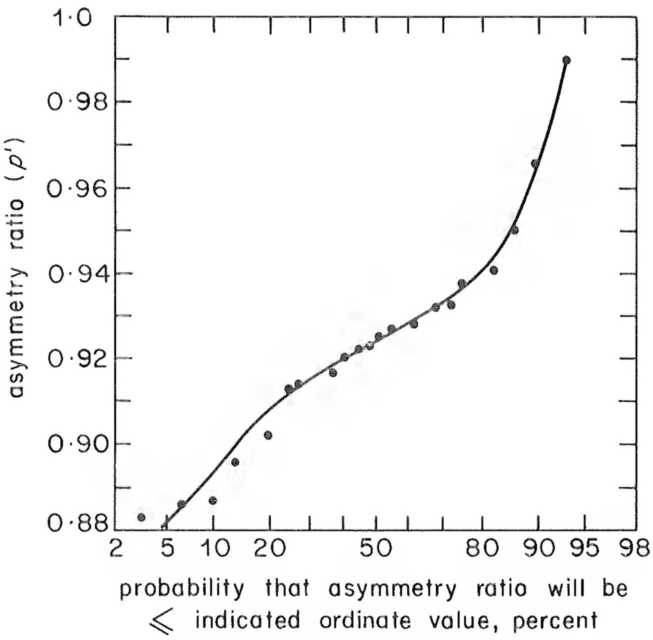


Fig. 15 - CSI 1 kW lamp: asymmetry ratio characteristics for beam-centre light

supply and running at its nominal rating, and 29 measurements were similarly made in the centre of the beam from the pre-focused unit. The broad-band photoreceptor spectral response was used in both cases. The results of these measurements are shown in Fig. 14 and 15 respectively in the form of probability relationships. It can be shown[2c] that under the operating conditions corresponding to Figs. 6 and 9, ripple asymmetry will not give rise to picture luminance fluctuations if the asymmetry ratio is greater than or equal to 0·941 using diffused light or 0·924 using beam-centre light.* Reference to Fig. 14 and 15 shows that the probabilities of such asymmetry ratio values occurring are 0·15 and 0·50 respectively; in other words, there is a 'one-in-seven' chance, using diffused light, that ripple asymmetry could give rise to picture luminance fluctuations, and an 'evens' chance of this occurring using light from the beam centre. In the case of the operating conditions corresponding to Figs. 8 and 11, ripple asymmetry will not give rise to picture luminance fluctuations[2d] if the asymmetry ratios are greater than or equal to 0·984 and 0·986 for diffuse or beam-centre light respectively. Again, reference to Figs. 14 and 15 shows that the probabilities of occurrence of such asymmetry ratios are 0·67 (say 'two in three') and 0·93 (say 'thirteen in fourteen') respectively.

In the case of the operating conditions shown in Fig. 7 and 10, ripple asymmetry is not significant[7] in producing picture luminance fluctuations over and above those produced by the ripple component itself. Fortunately, present-day operational practice in Europe (and to some extent on the American continent when generators independent of the 60 Hz public supply can be used to power

* These two values correspond to the two different values of ripple ratio (see Section 2).

the lamps) is represented by these operating conditions. In a larger number of cases, therefore, the presence of ripple asymmetry should not pose a problem. Nevertheless it must be remembered that ripple asymmetry may be significant in giving rise to picture luminance fluctuations under the particular operating conditions shown in Figs. 6, 8, 9 and 11, and that in particular the conditions shown in Figs. 8 and 11 should be avoided.

5. Conclusions

The observed magnitude of the intensity ripple component in light from the CSI 1 kW lamp depends on the frequency of the alternating lamp supply, the waveform of the current passing through the lamp (and therefore on the alternating supply waveform and the ballasting arrangements), the power dissipated in the lamp and the spectral characteristics of the equipment used for the measurement of the intensity variations. The film exposure variations, which can occur when the lamp is used as a light source in motion-picture film work, may be reduced to acceptable limits by suitable combinations of lamp supply frequency, camera frame frequency and camera shutter angle. In general terms, no significant film exposure variations should occur if the lamp supply frequency exceeds 750 Hz (for camera shutter angles greater than 160°) but there remains a slight risk that such exposure variations may remain significant in scene areas illuminated by light in the centre of a well-focused beam unless the supply frequency exceeds 1000 Hz.

In a large number of filming operations, using camera frame frequencies of 24 Hz or 25 Hz, lamp supply frequencies of 48 Hz or 50 Hz respectively, and camera shutter angles in the region of 180°, the presence of ripple waveform asymmetry will not give rise to significant film exposure variations. Ripple asymmetry may however be great enough to cause film exposure variations, leading to significant picture luminance fluctuations, if lamp supply frequencies of 60 Hz or 62·5 Hz respectively are used.

It should be emphasised that the predictions of the operating conditions under which picture luminance fluctuations should remain imperceptible (see Sections 3 and 4) are based on theoretical considerations.

6. References

1. TAYLOR, E.W. Some aspects of the use of metal-halide discharge lamps for film lighting. BBC Research Department Report No. 1976/2.

2. TAYLOR, E.W. Film lighting using metal-halide lamps: some operating conditions giving freedom from picture luminance fluctuations. BBC Research Department Report No. 1977/19.

   2a Ibid. Section 3.2.
   2b Ibid. Section 4.
   2c Ibid. Charts 25 and 29.
   2d Ibid. Charts 26 and 30.

3. TAYLOR, E.W. Metal-halide discharge lamps: the measurement of intensity ripple and a note on operation at high supply frequencies. BBC Research Department Report No. 1977/23.

   3a Ibid. Appendix.
   3b Ibid. Section 4.2.
   3c Ibid. Section 2.3.

4. ALDWORTH, R.C. The development and application of metal-halide lamps for color filming and television. *J. Soc. Motion Pict. Telev. Engrs.*, 1975, **84**, 2, pp. 70 – 76.

5. ALDWORTH, R.C. The application of CSI lamps. *B.K.S.T.S. Journ.*, 1976, **58**, 7, pp. 198 – 201.

6. BOURNE, H.K. Discharge lamps for photography and projection. London, Chapman and Hall Ltd., 1948, Fig. 41, p. 115.

7. TAYLOR, E.W. Film lighting using metal-halide lamps: the effect of intensity ripple asymmetry. BBC Research Department Report No. 1977/8, Table 1.

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